ELEVATING 4G AND 5G INFRASTUCTURE CONNECTIVITY

ABSTRACT

5G-NR and broadband 4G-LTE base-stations are raising the requirements placed upon power amplifiers and other RF components used in cellular infrastructure. NanoSemi's Linearization and Characterization Technologies elevate the performance of the entire RF signal chain to meet these evolving requirements.

Elevating Infrastructure Connectivity

Cellular infrastructure is becoming increasingly broadband. 5G-NR, the successor to 4G -LTE, is breaking new ground with an objective of delivering 5 Gbps to each user. To achieve this rate, 3GPP is specifying the 5G-NR component carrier to be 100 MHz as opposed to 20 MHz used in 4G/LTE. 5G-NR also has two spectrum allocations; Sub 6 GHz and mmW (millimeter wave). mmW is particularly challenging as bandwidths up to 800 MHz are expected with carrier aggregation.

New 4G-LTE base-stations are also being required to support broadband operation as they must be upgradable to 5G-NR. In addition, multi-band operation (e.g. Band 1 and Band 3) with a single power amplifier is becoming a requirement.

In order to accommodate these increasingly broadband requirements, regulators are making more contiguous spectrum available[1]. Numerous countries are assigning 5G-NR bands in the 3.3 - 3.8 GHz range; China and Japan are considering 4.5 - 5 GHz, and a growing number of countries are considering the 3.8-4.2 GHz range. 3GPP R16 specifications are also considering 5G in the UNII unlicensed bands where potentially over 1GHz of spectrum is available. In addition, radio access sharing and indoor DAS (Distributed Antenna Systems) will place multiple operators into a single RRH (Remote Radio Head), thus requiring broadband specifications of up to 400 MHz. All these trends place a premium on efficient broadband operation for wireless infrastructure.

⇨ New base-station requirements are driving 400 MHz support for sub 6-GHz base-stations and Remote Radio Heads and up to 800 MHz for mmW access points.

Existing Cellular Infrastructure is Challenged

These broadband 4G-LTE and 5G-NR waveforms are also required to meet stringent performance specifications. Specifically, 3GPP puts constraints on adjacent channel performance measured by the Adjacent Channel Leakage Ratio (ACLR), which is defined as the ratio of the transmitted power to the power in the adjacent radio channels. The specification for sub 6-GHz MIMO base-station is -45 dBc. However, the requirement of the most recently deployed base-station systems is driven by the operating band unwanted emissions (OBUE) level, starting at -15 dBm/MHz. Unlike 3GPP, FCC requires starting emission level at -13 dBm/MHz, and it becomes 3 dB more stringent as the number of antenna elements doubles. In addition, higher data rates in turn requires higher modulation rates (e.g., 256 QAM), which subsequently places a premium on achieving high linearity as measured by the Error Vector Magnitude (EVM).

Another trend is combining disparate bands into one RRH, which is being driven by increasingly cluttered cell towers. As of the writing of this paper, there are over 30 LTE FDD bands and 20 LTE TDD bands in sub 6-GHz spectrum[2]. While many of the bands are adjacent to each other ("extended bands"), many bands are spectrally far apart which traditionally has required dedicated radio chains including power amplifiers and other radio components. In order to reduce tower space, combining these radio chains is highly desirable as depicted in Figure 1 below. The NanoSemi Linearizer™ enables the combination of multiple transmit chains into a single Tx architecture and hardware, thereby reducing the cost of power amplifiers, antennas, and tower space. A multi-band solution based upon NanoSemi's Linearization can reduce the cost of RRH components by 40% or more. The key is enabling the transmit chains to implement very broadband signals while still meeting 3GPP ACLR specs and not desensitizing the receivers.

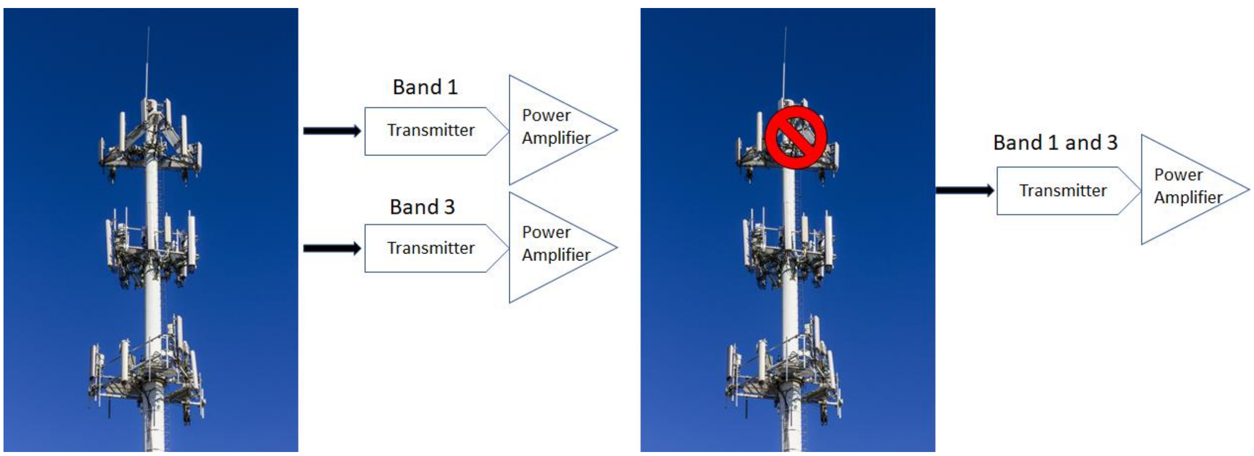

Figure 1: By combining Band 1 (2110 - 2170 MHz) and Band 3 (1805 - 1880 MHz) into a single radio head, tower space can be created

What does NanoSemi Bring to Solve These Problems?

Traditional approaches to linearization such as DPD with generalized memory polynomials become increasing complex as bandwidth scales. NanoSemi's Linearization can address these 5G-NR broadband signals at significantly reduced complexity, size, and power consumption. NanoSemi's implementation is inherently broadband and can meet the ACLR and EVM specifications at the wider bandwidths required by 5G-NR while concurrently improving system power efficiency and power output. As shown

in the Figures 3 and 4 below, NanoSemi's Linearizer achieves 400 MHz for a Band 42 5G-NR waveform while exceeding 3GPP specifications. In addition, NanoSemi's machine learning based estimation predicts and adapts to changes in the RF chain caused by temperature, load variation and other factors. Estimation is implemented either in logic gates or processor at a fraction of DPD implementation size and power.

Common to these requirements is the need to improve the performance of the signal chain, including the data converters, PAs and other system components. This is best done by linearization with advanced digital signal processing. NanoSemi brings linearization to new levels by using a "smart learning" approach which automatically characterizes the signal chain including the PAs. It identifies nonlinear components and other non-ideal impairments in dynamic system operation across the full signal chain of a radio and analyzes their impact on system performance. A corresponding mathematical model is then created, including nonlinear transformations. This approach has the following benefits:

- Automatically characterizes and models the signal chain from baseband, mixed-signal to RF domains
- PA agnostic: GaN, LDMOS, GaAs, SiGe, CMOS
- Works with any RF for mobile devices, customer premises equipment and base stations
- Unprecedented bandwidth with reduced sampling rate

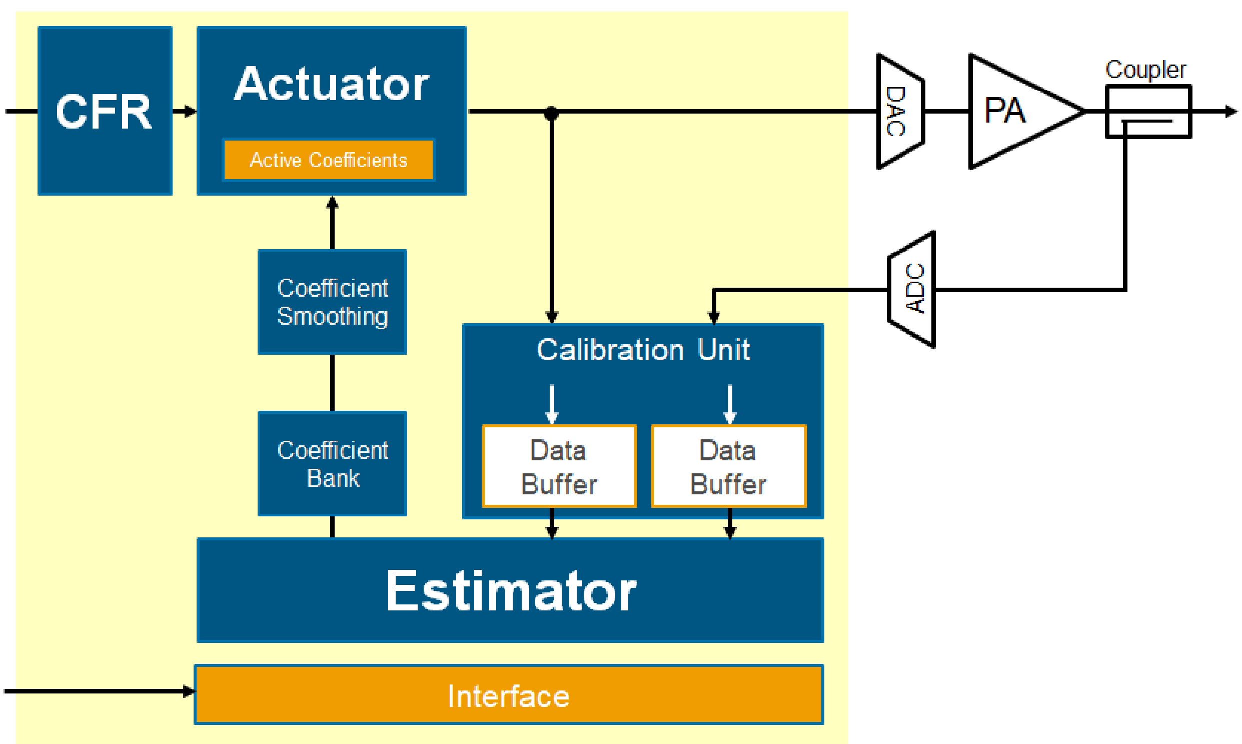

Figure 2: NanoSemi's Linearizer IP blocks reside within a baseband processor or transceiver

As shown in Figure 2, the NanoSemi Linearizer is composed of multiple IP blocks. The Actuator, which performs the forward path correction, uses advanced and patented mathematical representations in lieu of generalized memory polynomials (GMP). GMP structures become computationally expensive (i.e. larger silicon implementation size and higher power consumption) especially if the PA is driven close to saturation in order to maximize power efficiency. Also, imperfect components in the front-end module (FEM) can result in leakage from Tx to Rx creating an impairment. A typical DPD doesn't correct for such impairments; NanoSemi's linearization does.

Compared to conventional DPD solutions, the NanoSemi linearizer requires an oversampling ratio of 2.5, instead of 5 or higher. For example, if the instantaneous signal bandwidth is 100 MHz, NanoSemi's solutions typically require the transmitter sampling rate to be 250 MS/s. The reduced sampling rates reduces the power consumption as implemented in a FPGA or silicon.

As shown in Figure 2, NanoSemi's Linearizer also includes a real time Estimator block based upon machine learning which controls the Actuator, also known as the compensator. To enable the use of higher quality compensators, NanoSemi does not rely on the standard linear algebra solution to the least squares optimization problem. Instead, it employs other algorithms, depending on the application.

A comparison of the NanoSemi Linearizer to Traditional DPD and Envelope Tracking (another technique used to improve amplifier efficiency) is shown in Figure 3 below:

	Envelope Tracking	**Traditional DPD**	**NanoSemi Linearization**	**Notes**
Bandwidth >100MHz	🟡	🟡	🟢	ET requires power supply switching >2-3X signal bandwidth
Improve PA Efficiency	🟢	🟢	🟢	ET and traditional DPD optmized for linearizing low bandwidth signals
Increase Average Power	🟡	🟡	🟢	DPD based upon GMP needs to back off further from Psat-PAPR
Improve Linearity & ACLR	N/A	🟡	🟢	ET focuses on Effiency improvement through power supply modulation. Needs to be coupled with Linearizer or DPD to improve ACLR and EVM
Improve EVM	N/A	🟡	🟢	
Implementation Size	🔴	🟡	🟢	DPD based upon GMP increases with Bandwidth: ET requires additional circuit blocks & highly linear switching power supply
RF Chain Characterization	N/A	N/A	🟢	NS characterizes entire signal chain from data converter to PA; able to linearize non PA components

Figure 3: NanoSemi's Linearizer compared to GMP based DPD and envelope tracking

- ⇨ Compared to base-stations without any form of DPD or linearization, NanoSemi's Linearization can reduce the radio subsystem power consumption by 80%.
- ⇨ Compared to GMP based DPD implementations, NanoSemi can reduce the power consumption by 33%.

Upon request and NDA, NanoSemi can provide the details behind this analysis.

The Results

As stated in the introduction, trends in wireless infrastructure are forcing radio systems and RRH to support bandwidths of 200 MHz or more. As can be seen in the figures below, the NanoSemi Linearizer enables a nearly 27 dB ACLR improvement with a 400 MHz 5G-NR waveform, exceeding the 3GPP ACLR specification (Figure 4) while at the same time meeting the EVM specifications required of 256 QAM (Figure 5).

5G NR with 4x100MHz Carriers

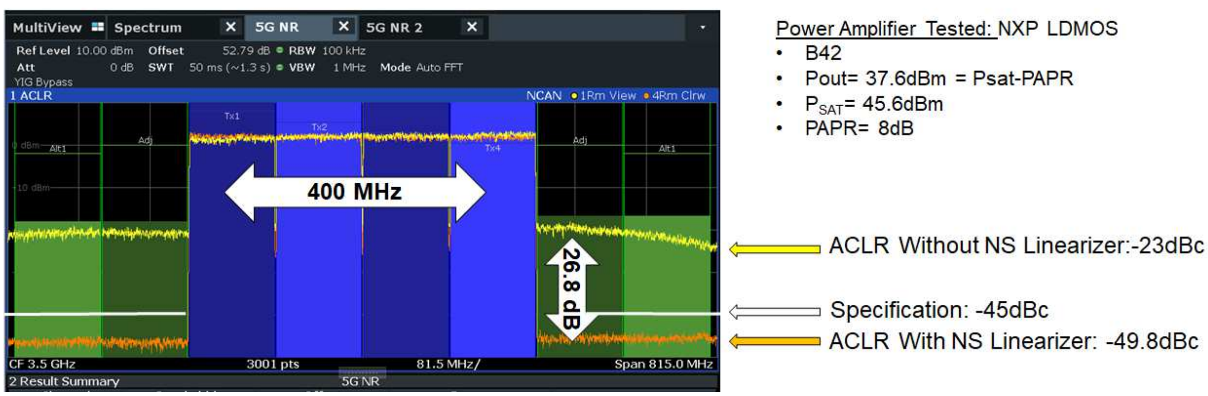

Figure 4: 400MHz 5G-NR ACLR test results with commercial amplifiers

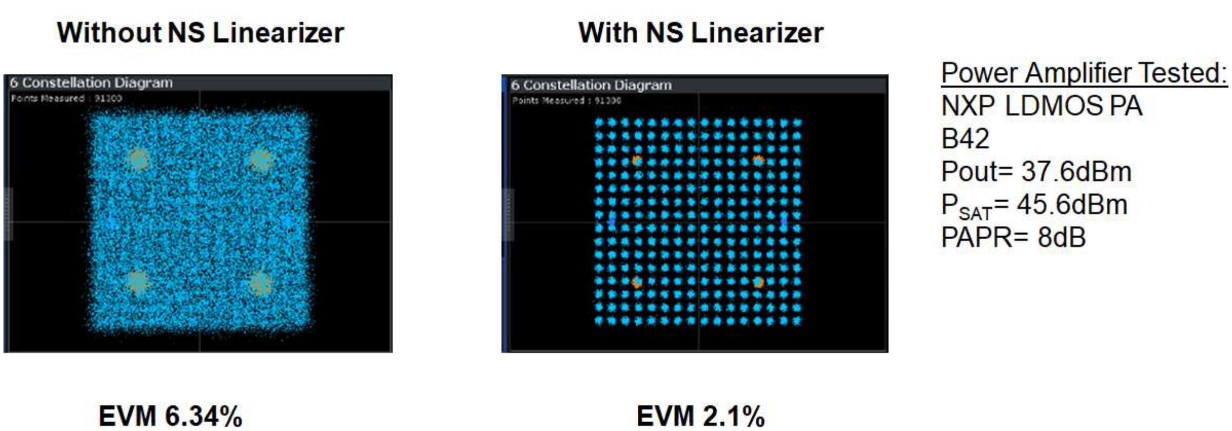

Figure 5: 400MHz 5G-NR EVM test results

These benefits also extend into multi carrier LTE with massive MIMO. Figure 6 shows the ACLR improvement on a 3.5 GHz m-MIMO waveform with 200 MHz instantaneous bandwidth signal (10x 20 MHz LTE carriers). This testing was conducted with Gallium Nitride (GaN) PAs operating at 35 dBm average output power level. The measured ACLR of -51 dBc exceeds 3GPP requirements by 6 dB.

Figure 6: ACLR improvement of 25 dB in a 200 MHz OFDMA waveform (10x20 MHz LTE). This is also indicative of a 2X100 MHz 5G waveform showing a -50.8 dBc ACLR, 5 dB better than 3GPP specification for ACLR.

As depicted in Figure 1, dual band and multi-band operation enables RRHs to be combined, thereby freeing up tower space and reducing cost. The NanoSemi Linearizer enables the combination of multiple transmit chains into a single transmit architecture and hardware, thereby reducing the cost of power amplifiers, antennas, and tower space. This is particularly useful for existing LTE systems which are overwhelming the limited supply of tower space. In order to achieve this goal, the noise and interference between desired bands should be suppressed as depicted in Figure 7 below for bands 1 and 3 which is one of the more difficult cases. Other bands that offer opportunities for combination include Band 13 (746 - 756MHz) and Band 5 (869 - 894MHz) or Band 14 (758 – 768MHz) and Band 8 (925 - 960MHz).

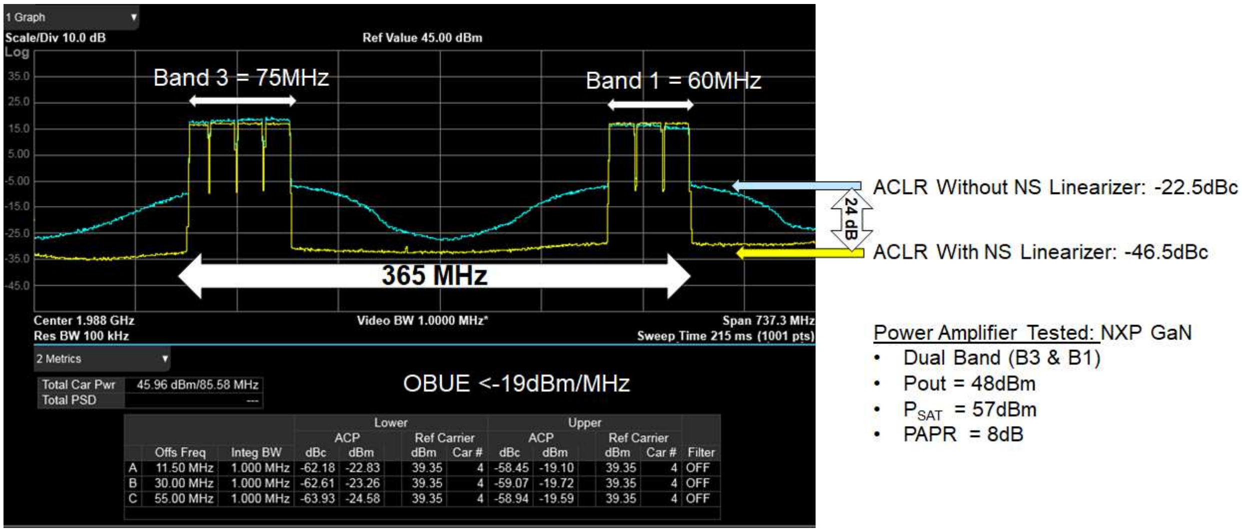

Figure 7: Suppression of inter-band noise and interference in a dual band (bands 1 and 3) signal placed through a single Power Amplifier.

Conclusion

The evolution of 3GPP standards is elevating radio system requirements. The radio chain is the interface between the modem and spectrum and is where the "rubber meets the road". Improving radio chain performance is critical to increasing data rates, spectral and power efficiencies as well as accommodating increasingly broadband waveforms. NanoSemi's Linearization and Characterization techniques improve radio chain power efficiency and signal cleanliness at unprecedented bandwidths. The small implementation size is cost effective for integration into ASICs or FPGAs.

For more information, please contact us through our web page:
http://www.nanosemitech.com/contact-us/

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